E-LEARNING SYSTEM FOR EXPERIMENTS INVOLVING CONSTRUCTION OF PRACTICAL ELECTRONIC CIRCUITS

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ABSTRACT

This paper proposes a novel e-learning system for technical experiments involving the construction of practical electronic circuits; this system would meet the various demands of individual experimenters. This mixed mode is beneficial for practical use in that an experimenter who does not have sufficient circuit components for circuit making can still learn to construct practical, large-scale circuits and evaluate their behavior using virtual measurements and a simulation technique involving circuit translation into SPICE. The proposed system is expected to be applicable to various educational media (e.g., e-Learning, mobile learning, virtual laboratories). The proposed system is constructed by combining real and virtual circuit making systems, and performs the improved circuit recognition of images including both real and virtual circuit regions. The usefulness and effectiveness of the proposed system were evaluated by analyzing circuits made by ten university students in an actual class.

KEYWORDS

e-Learning system for experiments, electronic circuit making, circuit translation into SPICE

1. INTRODUCTION

Teaching and learning the design and construction of electronic circuits is important in the field of technology education. Recently, several education support systems have been developed to improve students' understanding of electronic circuits and circuit-making ability. The stand-alone simulation systems (Abramovitz, 2011; Fitch, 2011) and virtual laboratories (Gurkan, 2008; Oliver, 2009) are useful for students lacking experimental facilities. However, these conventional systems cannot cope with the wide variety of circuits constructed by individual experimenters because they are based on all-purpose or ready-made learning tools and apply only to specific circuits within a subject area.

To overcome these disadvantages, a distance learning system has been developed in the present study for experiments involving both real circuit making (RCM) and virtual circuit making (VCM) (Takemura, 2012). An experimenter who has the required circuit components but lacks measurement equipment can learn circuit making and analyze circuit behaviors using the virtual measurement technique of the RCM system. Distance learning using the VCM system is useful and effective for users lacking both circuit components and measurement equipment for making and analyzing real circuits. Both RCM and VCM systems are applicable to various educational media (e.g., virtual laboratories and e-Learning). However, there is a need for systems utilizing which users can learn to construct larger-scale circuits and various practical circuits. To deal with the shortcomings of the stand-alone systems mentioned previously, this study proposes a novel learning mode that combines RCM and VCM. This proposed mixed mode performs the improved circuit recognition of images including both real and virtual circuit regions. The mixed mode enables an experimenter who lacks the necessary circuit components and measurement equipment to learn the construction of practical and large-scale circuits and evaluate circuit behavior.

2. METHODOLOGY

Figure 1 illustrates the proposed e-Learning system for experiments involving the design and construction of practical, large-scale circuits. This system consists of individual users' computers and a remote analysis system. Individual users can choose a preferred mode from three learning modes (VCM, RCM, and the mixed mode) depending on the required purpose or environment (subsections 2.1–2.3). To support circuit design and construction, each student uses a computer to transmit the circuit image to an analysis system that runs on the internet. The analysis system recognizes the circuit construction using image processing techniques and translates the structure of the circuit into a general circuit description language (SPICE) (Rabaey, 2012). This SPICE translation technique indicates the working of the circuit and enables virtual measurement without real measurement equipment, and it can identify the incorrect components present in the circuit (Takemura, 2011). This is an important step that aims to improve the efficiency and prevent the occurrence of serious accidents such as electric shocks or fire.

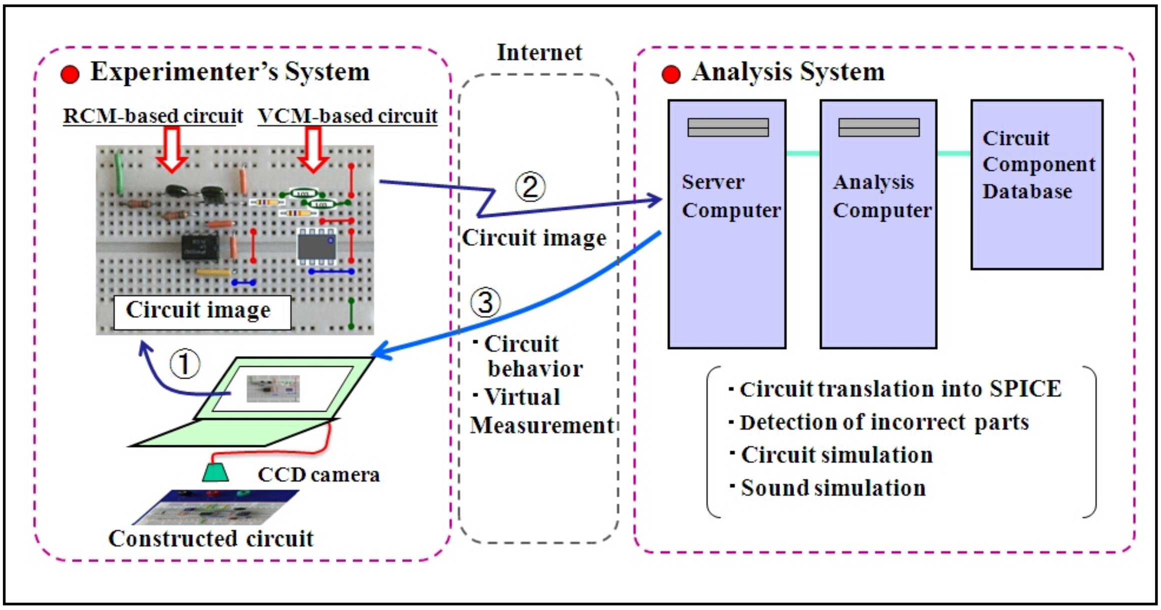

Figure 1. Schematic of the proposed e-Learning system for experiments involving circuit making.

2.1 VCM Mode

The VCM mode of the system is useful for students lacking circuit components, measurement instruments, or facilities (e.g., laboratories). The VCM mode (Takemura, 2012) enables individual experimenters to use graphics editors, which are installed on a user's computer. Therefore, this system does not require the use of proprietary graphics software. Each experimenter can download virtual circuit components and a template circuit-board image from the analysis system. The connections of circuit components on a virtual circuit can be indicated by placing the virtual circuit components and the characters representing their parameters (e.g., IC resistance and capacitance) on the template circuit-board (breadboard) image using the experimenter's preferred graphics editor. The experimenter indicates the virtual-circuit connections by drawing colored lines on the template image using a graphical user interface (GUI) and saves the image of the virtual circuit in a commonly used file format (e.g., JPEG and BMP). The virtual circuit image is transmitted to the analysis system, and the analysis system performs circuit recognition using image processing techniques (pattern matching) by comparing the components in the virtual-circuit image with each circuit component available in the server database of the analysis system. The analysis system translates the virtual circuit into SPICE without errors because circuit recognition is based on the input data of the virtually constructed circuit.

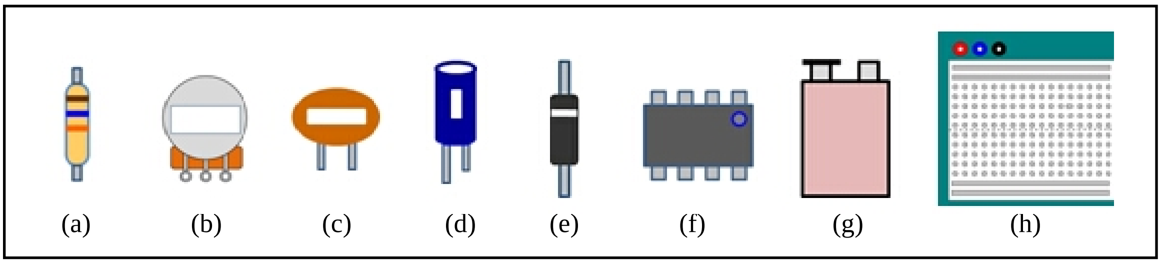

Figure 2. Circuit components for the VCM mode: (a)–(f) virtual circuit components prepared for connection on the circuit board image (resistor, potentiometer, capacitor, electrolytic capacitor, diode, and IC, respectively), (g) 9V battery, and (h) circuit board image used to construct a virtual circuit.

2.2 RCM Mode

An experimenter having the circuit components necessary for circuit making can learn to construct a circuit and analyze its behavior using the RCM virtual measurement mode (Takemura, 2012). The experimenter transmits the image of the constructed circuit to the analysis system. The analysis system performs pattern matching between the virtually constructed circuit (drawn using the VCM system) and the circuit constructed using the RCM mode. This enables the analysis system to automatically differentiate the layout of each device and determine the circuit wiring. In addition, the analysis system performs circuit recognition on the basis of the training data obtained from this approximate differentiation and the circuit device database. The pattern matching process between the virtual circuit and the real circuit improves the accuracy of circuit recognition and SPICE translation and decreases the computational cost.

2.3 Mixed Mode

The mixed mode of the proposed e-Learning system for practical circuit making can translate a circuit image consisting of both real and virtual circuit components. This mode is useful for experimenters who do not have sufficient real circuit components needed to make a complete circuit because it enables them to study the construction of practical and large-scale circuits through the following steps (A)–(E):

(A) An experimenter designs and constructs a virtual circuit using virtual circuit components downloaded from the analysis system and saves an image of the VCM circuit.
(B) The experimenter constructs a partially real circuit using real circuit components and saves an image of the incomplete RCM circuit.
(C) Using a graphics editor, the circuit image is completed by placing the VCM components on the incomplete RCM image.
(D) The analysis system automatically indicates the incorrect components on the circuit image on the basis of the difference between the translated SPICE information obtained from the images saved in (A) and (C).
(E) The experimenter can study the behavior of the circuit on the basis of SPICE information. Measurement instruments are not needed to check circuit behavior.

In this study, the image analysis technique for circuit recognition was improved to make it usable for circuit images including both real and virtual circuit regions. Concretely, the database of the circuit components for pattern matching techniques was increased to cover both RCM and VCM modes, and a morphological operation (Haralick, 1987) is used to detect the connected position of each component on the breadboard and adjust the size of the discriminated virtual components on the basis of the size of real components.

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2.4 Experimental Methodology

The proposed system was evaluated by analyzing the circuits designed and constructed by ten experimenters in an actual class at Tokyo University of Agriculture and Technology. Figure 3(a) shows the diagram of a practical sound processing circuit for electric guitars to be constructed using the mixed-mode of the proposed system. The physical circuit components to be used to construct a simple circuit (an active filter) (Fig. 3(b)) were provided to each student on the assumption that experimenters who learn circuit construction using an e-Learning system do not have sufficient circuit components. Therefore, the circuit components provided to the students were not sufficient to construct the circuit shown in Fig. 3(a), and thus, the mixed mode of the proposed system is indispensable to the construction of the complete circuit.

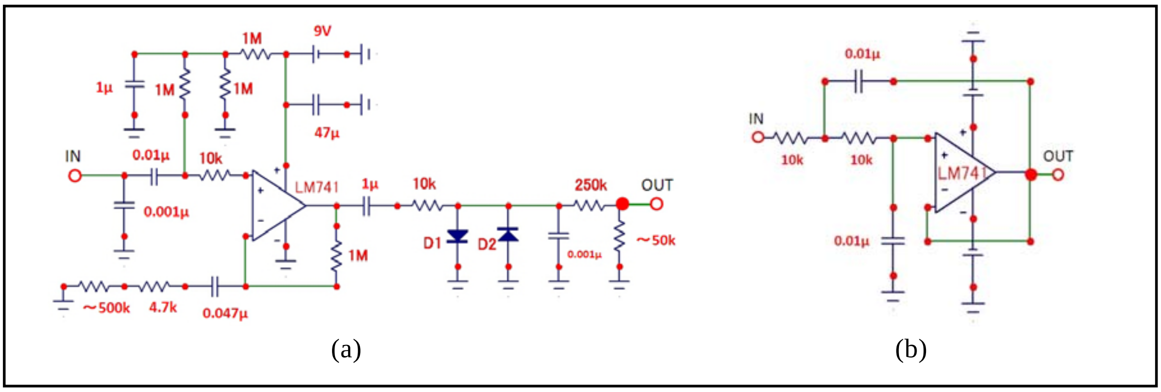

Figure 3. Circuit diagrams to evaluate the proposed system: (a) circuit to be constructed using the mixed mode of the proposed system and (b) circuit to be constructed by individual users using the available circuit components.

3. RESULTS AND DISCUSSION

Figure 4(a) and (b) show examples of the circuit designed using the VMC mode and the circuit constructed using the proposed mixed mode by an experimenter, respectively. Figure 4(c) shows an example of the simulation results (sound waves of the input and output signals) obtained from the SPICE translation of the circuit constructed using the mixed mode. The analysis system provided simulated the sounds and provided the simulation results, enabling the experimenter to examine the behavior of the circuit and the effect of sound processing (synthesized sound) on the basis of the virtual circuit.

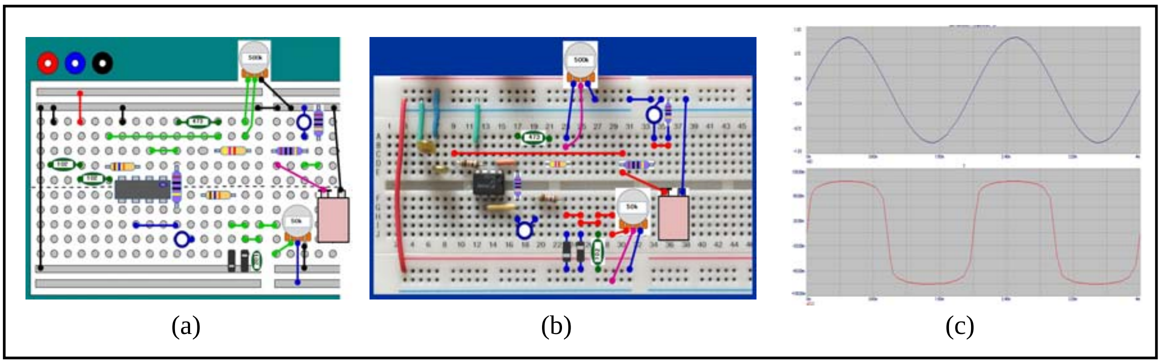

Figure 4. Results of circuit construction using the mixed mode: (a) circuit designed using the VCM mode, (b) image of the circuit constructed using the proposed mixed mode; (c) SPICE simulation based on circuit translation(sound waves of the input and output signals).

The proposed system was evaluated by analyzing the circuits constructed by ten students at Tokyo University of Agriculture and Technology. The following positive responses, which pertain to the usefulness and efficiency of the proposed system, were obtained from all students:

- The mixed mode of the systems is useful because it enables e-Learning of topics such as circuit design and experiments involving practical circuit making.
- The proposed system is instructive, and individual students can study practical circuits. The system enables enlargement and optimization of a physically constructed circuit using the mixed mode of the e-Learning system.

However, there were also a few technical disadvantages and suggestions for improvement:

- A remote educational system to study digital circuits is expected.
- The size of the experimenter’s system should be reduced.

4. CONCLUSION

This paper deals with a novel e-learning system for technical experiments involving the construction of large-scale, practical electronic circuits. The proposed mixed-mode system is developed by combining RCM and VCM systems. The usefulness and effectiveness of the system were verified by analyzing electronic circuits constructed by ten students in an actual university class. Positive responses, which pertain to the usefulness and efficiency of the proposed system, were obtained from all the students. The following steps are necessary to practically realize the proposed system:

- A mobile communication tool instead of an experimenter’s computer is expected to reduce the size of the system.
- Computational costs for circuit recognition procedure should be decreased.

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